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ABSTRACT

The body mass index (weight in kilograms/height in square meters) is a common surrogate for fatness. With the advent of bioelectrical impedance analysis, more precise measurement of fatness in populations is now possible. We measured height, weight, and percentage that is fat by bioelectrical impedance analysis in 2032 adults, ages 31 to 92, participating in the Framingham studies. Body mass index was a poor predictor of fatness in women ($R^2 = 0.55$) and men ($R^2 = 0.38$), and was imprecise (standard error of estimate = 5 percentage points). The relationship between percentage fat and body mass index was quadratic in both sexes, and was altered by age in women ($P < .0001$) and, to a lesser extent, in men ($P < .027$). These data suggest that body mass index is an imprecise measurement of fatness compared with bioelectrical impedance. (*Am J Public Health.* 1995;85:726-728)

Predicting Body Fatness: The Body Mass Index vs Estimation by Bioelectrical Impedance

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Introduction

Body composition is a powerful predictor of mortality and morbidity in humans.¹ The most common estimate of body composition in populations has been the body mass index, which was actually developed as a measure of weight that is independent of height and not as an index of obesity.^{2,3} It is most commonly computed as weight in kilograms/height in square meters. Yet this entails a potential misclassification of fat content by body mass index: a person may be overweight but not overfat, or underweight yet overfat.

The advent of bioelectrical impedance analysis promises at least one other measure of body composition that can be applied to large populations. Bioelectrical impedance analysis is inexpensive, easy to use, free of observer bias, and precise.^{4,5} We examined the ability of body mass index to predict the fat content (percentage that is fat) of 2032 adult participants in the Framingham Heart Study and Framingham Offspring Study, as estimated by bioelectrical impedance analysis.

Methods

Body composition was measured in the 22nd examination cycle of the Framingham Heart Study and 5th examination cycle of the Framingham Offspring Study. Of the original 5209 heart study participants, approximately 880 survivors attended the 22nd examination cycle, with an average age of 79 years (maximum age = 92); only ambulatory heart study subjects were included. The Offspring Study is an epidemiological study that began in 1971 by enrolling the children of

the original Heart Study cohort and their spouses. The population comprises 2296 men and 2554 women, with an age range of 20 to 89 (mean age = 54 years). The data presented here are those obtained for the first 2032 participants of both studies, 335 from Framingham Heart Study and 1697 from Framingham Offspring Study. The current sample is representative of the two cohorts and is identical to them in sex, age structure, and race.

Height was measured to the nearest 0.25 in, using a stadiometer. Weight was measured to the nearest 0.25 lb using a standing beam balance, with subjects wearing robes and no shoes, in keeping with practices of previous examination cycles. English measures were converted to metric after data entry. Bioelectrical impedance analysis was carried out using the standard tetrapolar technique according to the manufacturer's instructions for distal electrode placement on the right hand and foot (BIA-101A, RJL Systems, Detroit, Mich). Fat-free mass was calcu-

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TABLE 1—Description of Study Population (Unadjusted Mean \pm SD)

Parameter	Women (n = 1105)	Men (n = 927)
Age, y	58.9 \pm 13.6	56.4 \pm 12.2
Weight, kg	68.8 \pm 14.6	85.4 \pm 13.7
Height, cm	158.0 \pm 6.4	171.7 \pm 7.0
Body mass index, kg/m ²	27.6 \pm 5.6	28.9 \pm 4.0
% fat	37.7 \pm 7.8	29.4 \pm 6.1
Waist-to-hip ratio	0.83 \pm 0.08	0.96 \pm 0.09

lated from resistance, reactance, height, weight, age, and sex using the equations of Lukaski.⁶ The correlation between fat-free mass by bioelectrical impedance analysis and by hydrodensitometry in healthy adults under age 50 has been reported to be 0.98, with a standard error of the estimate (SEE) of 2.29 kg.⁶ Bioelectrical impedance analysis was further validated in a subset of elderly subjects (n = 466, mean age = 78 years) using dual-energy x-ray absorptiometry, and a correlation for fat-free mass was found of 0.85 for men and 0.88 for women, with SEEs of 3.5 kg and 2.5 kg, respectively. Thus, while bioelectrical impedance analysis was less precise and accurate in the elderly than in young subjects, it was still a valid method of estimating body composition (Roubenoff R, Kiel DP, Hannan MT, Dallal GE, Wilson PWF, Harris TB; unpublished observations). A detailed report of the technical aspects of these validation studies is now in preparation.

Normality of the data was ascertained visually and statistically. The ability of body mass index to predict fatness from bioelectrical impedance analysis was analyzed by multiple linear regression (BMDP 2R, BMDP Statistical Software, Los Angeles, Calif). The effect of age on this relationship was examined by decade of age using linear regression by groups (BMDP 1R). Participants in both studies were considered together. Results were considered statistically significant when the observed two-tailed significance level was $P < .05$.

Results

There were 1105 women and 927 men available for analysis (Table 1), with

mean (\pm SD) ages of 58.9 \pm 13.6 and 56.4 \pm 12.2, respectively. The subjects tended to be overweight, with both body mass index and percentage fat above US medians.⁷ Mean percentage body fat from bioelectrical impedance analysis increased with age in both sexes, peaking in the 60s for women and in the 50s for men, and then declining somewhat (Table 2). In contrast, waist-to-hip ratio, a measure of fat distribution, increased linearly with age in both sexes. However, mean body mass index remained unchanged across all decades of age for both sexes.

Ignoring age, there was a quadratic relationship between body mass index and fatness for both men and women (Table 3). Body mass index itself explained 55% of the variability in fatness in women ($P < .0001$) but only 38% of the variability in men ($P < .0001$). The quadratic term, body mass index squared, explained an additional 5.5% of the variability in fatness in women ($P < .001$) and a small but still significant 0.5% in men ($P < .01$). The SEE of fatness using both indices was 4.8 percentage points in the men and 5.0 percentage points in the women, indicating that the estimate of fatness based on body mass index is very imprecise.

When age was grouped by decades and entered along with body mass index and body mass index² in regression analysis for the outcome of fatness, age altered the relationship between body mass index and fatness in the women ($F_{15\ 1087} = 5.22$, $P < .000001$) and, to a lesser extent, in the men ($F_{12\ 912} = 1.94$, $P < .027$).

Discussion

These data indicate that, when compared with an estimate of fatness based on bioelectrical impedance analysis, body mass index is imprecise, nonlinear, and biased by age, especially in women. The population studied was a large one (n = 2032), ranging in age from 31 to 92 years. Of note, the population tended to be overweight and overfat (Table 1) according to guidelines for desirable body composition.⁸ Compared with body mass index for the population from the first National Health and Nutrition Examination Survey, the mean body mass index for men in this study is in the eighth decile (80th to 89th percentile) of body mass index and for women, the seventh decile (70th to 79th percentile).⁹ The higher fat mass of our population may increase the importance of the quadratic term in our analyses inasmuch as fatness may increase faster than weight at higher total weights.

However, because the quadratic relationship held across all tertiles of weight and across decades of age (data not shown), we do not believe that the increased weight of our population invalidates these results. As shown in Table 2, mean body mass index did not change across the decades of age for this population. On the other hand, fatness among women increased between their 30s and 60s and then declined, while among men it peaked in the 50s and then declined slightly in later decades. In contrast, waist-to-hip ratio increased linearly with age in both sexes. These data suggest that fatness varies with age and that fat distribution becomes progressively more unhealthy with age (that is, close to 1.0), but that body mass index fails to capture both of these changes.

Fatness estimated by bioelectrical impedance analysis depends on regression equations created using another method, such as underwater weighing or dual-energy x-ray absorptiometry, in a population similar to the one under investigation.¹⁰⁻¹² We applied Lukaski's⁶ equations because they were developed across a wide age range. As noted in the Methods section, we examined the correlation between bioelectrical impedance analysis and dual-energy x-ray absorptiometry in a subset of elderly subjects and found a correlation of 0.85 for men and 0.88 for women. We did not repeat the published validation study of bioelectrical impedance analysis for younger adults⁶ because our population under age 50 is reasonably similar to Lukaski's and concern about the validity of bioelectrical impedance analysis is highest in the eldest subjects. However, even if all the potential errors of bioelectrical impedance analysis were present, their cumulative effect would probably be small in this healthy population. Hydration of lean mass in the elderly is close to normal (within 5%), and bioelectrical impedance analysis has performed remarkably well in various populations, even in extreme physiological conditions such as acquired immunodeficiency syndrome and in those requiring treatment in intensive care units.^{6,10,11,13,14} All our subjects, regardless of age, were ambulatory and able to come to the clinic for evaluation. Furthermore, the discrepancy between body mass index and bioelectrical impedance analysis occurred in all age groups, including those in which bioelectrical impedance analysis was well validated.

Additional support for these conclusions comes from several studies that

TABLE 2—Mean and Standard Deviation (SD) for Body Mass Index (kg/m²), Percentage Body Fat by Bioimpedance, and Waist-to-Hip Ratio for Women and Men,^a by Decade of Age

Decade	Women				Men			
	n	Body Mass Index	% Fat	Waist-to-Hip Ratio	n	Body Mass Index	% Fat	Waist-to-Hip Ratio
		Mean (SD)	Mean (SD)	Mean (SD)		Mean (SD)	Mean (SD)	Mean (SD)
30–39	61	27.2 (6.0)	34.7 (9.9)	0.80 (0.07)	62	28.6 (4.4)	27.4 (6.5)	0.92 (0.07)
40–49	257	27.0 (6.0)	36.0 (8.0)	0.81 (0.09)	237	29.1 (4.4)	28.8 (6.2)	0.95 (0.08)
50–59	287	27.8 (5.3)	38.7 (6.9)	0.82 (0.08)	276	29.2 (3.9)	30.1 (5.8)	0.97 (0.12)
60–69	237	28.0 (5.7)	39.5 (7.1)	0.84 (0.08)	206	29.0 (3.5)	29.8 (6.0)	0.97 (0.05)
70–79	176	27.9 (5.5)	37.2 (8.3)	0.86 (0.08)	110	28.3 (4.1)	29.2 (6.3)	0.98 (0.06)
80+	87	27.3 (4.5)	37.2 (7.7)	0.88 (0.07)	36			

^aMen in the seventh and eighth decades are grouped because of small sample size.

TABLE 3—Relationship between Percentage Fat as Determined by Bioelectrical Impedance Analysis and Body Mass Index (BMI) in All Subjects, without Adjustment for Age

Term	β	SE (β)	Partial R^2	P
Women				
BMI	.0321	.0020	.550	<.0001
BMI ²	-.0035	.0003	.055	<.001
Men				
BMI	.0197	.0038	.384	<.0001
BMI ²	-.0017	.0006	.005	<.01

compared body mass index with anthropometric and hydrostatic measures of fatness.^{2,3,15,16} These studies show a coefficient of determination (R^2) of fatness for body mass index ranging from 0.34 to 0.71 even in populations younger than ours. Thus, three methods that produce an assessment of body composition rather than relying on weight alone—bioelectrical impedance analysis, anthropometry, and densitometry—suggest that body mass index is a very imprecise indicator of body fatness. Despite concerns about the validity of bioelectrical impedance analysis when compared with sophisticated reference techniques, it remains the only technique that is unbiased, inexpensive, and applicable to large numbers of subjects with adequate precision. The case is strong that bioelectrical impedance analysis is superior to a weight-for-height index (i.e., body mass index) as a measure of body composition. □

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